Gamma Rays from Accreting Black Holes

Roger Blandford
KIPAC, Stanford

Accretors

* Protostars
* Planets
* Cataclysmic Variables
* X-ray Binaries
* Disk Galaxies!
* Active Galactic Nuclei
* Inactive Galactic Nuclei
* Gamma Ray Bursts**?**
* …

Traditional Disks are:

* Conservative
* Stationary
* Radiative
* Thin
* Fluid dynamical

Traditional Disk Power

Torque

Keplerian Disk

Angular Momentum

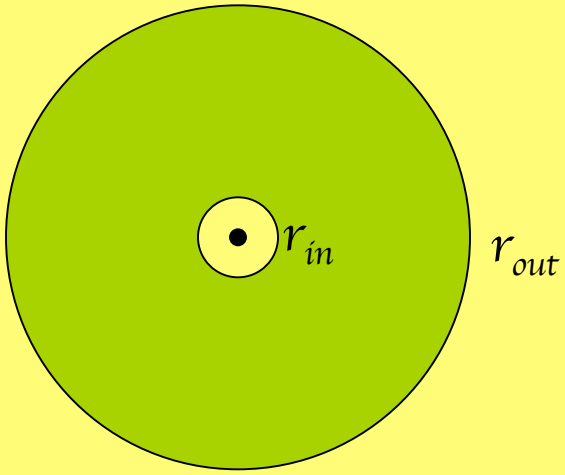
$$\frac{d}{dr}(G - \dot{M}L) = 0$$

Energy

$$\frac{dL}{dr} = -\frac{d}{dr}\left(G\Omega - \dot{M}E\right) = 3\dot{M}\frac{dE}{dr}$$

Dissipation

Binding Energy

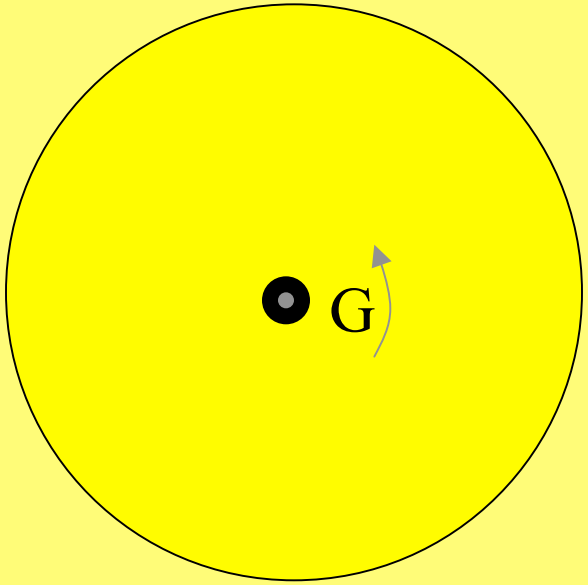


Non-conservative disks

* Outflows,winds, jets remove, mass, angular momentum, energy
* Thick (H~r/M)
  - Ion pressure $\dot{M} << \dot{M}_{Edd} = 4\pi M/\kappa$
    - Dissipated energy heats ions
    - Poor ion-electron coupling
    - Cold electrons don't radiate
    - Radio galaxies
  - Radiation pressure $\dot{M} >> \dot{M}_{Edd}$
    - Thomson scattering optical depth
    - Photons trapped within $r \sim \dot{M}\kappa/4\pi c$
    - Advected inwards
    - BALQs

Torque Transports Energy

Angular Momentum Transport



$$F_L = G - \dot{M}\, L \sim r^{1/2} \sim 0$$

Energy Transport

$$F_E = G\Omega - \dot{M}\, B \sim r^{-1} \sim 0$$

$$B = \frac{1}{2}V^2 + \Phi + W \sim \Omega L > 0$$

Bernoulli Function

Energy transport from small r
by torque unbinds gas at large r.

ADAF vs ADIOS

* Advection-Dominated Accretion Flow
  – Liberated binding energy advected across horizon

Quataert

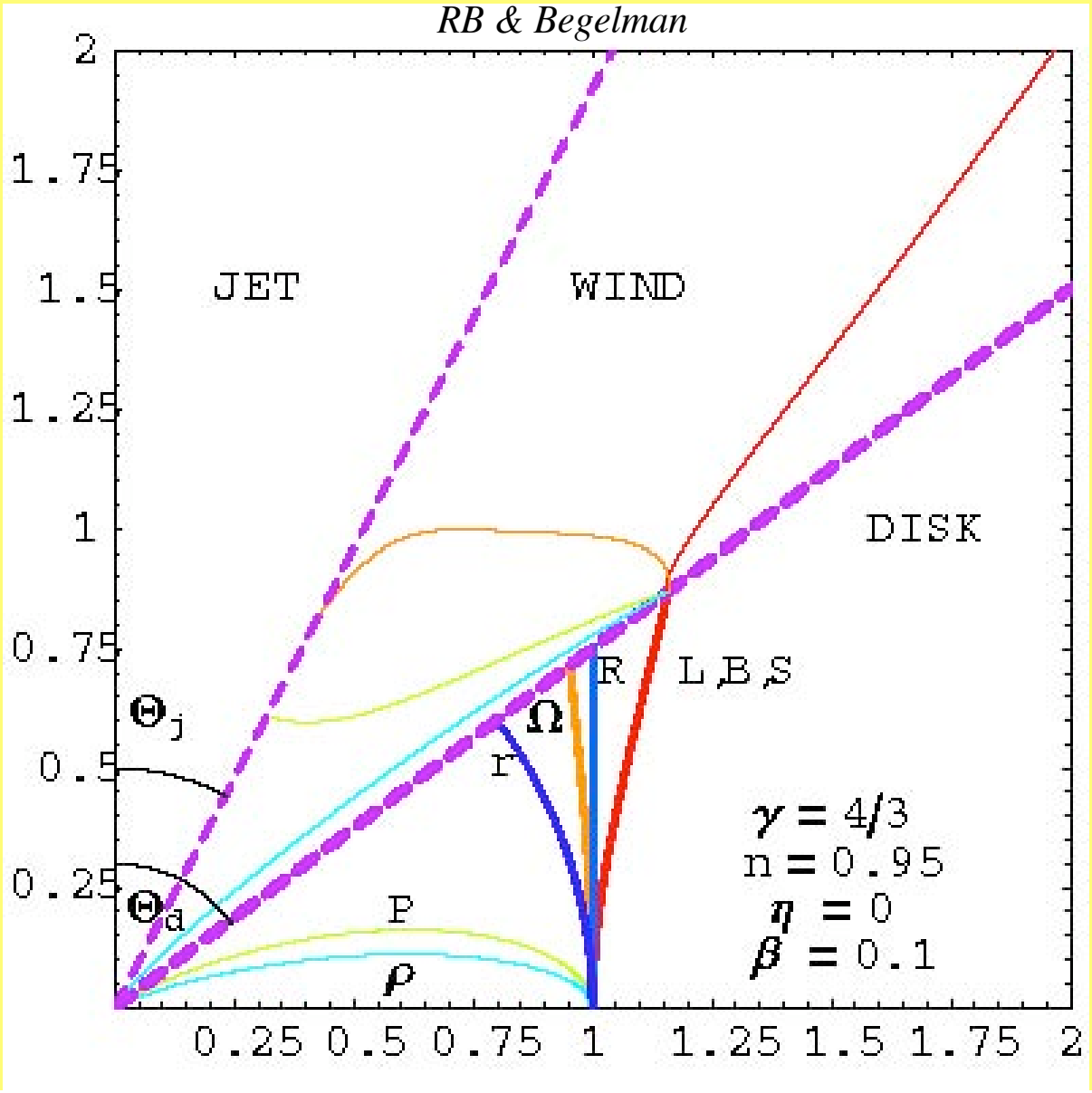
* ADiabatic Inflow-Outflow Solution
  – Liberated binding energy carried off in a wind
  – Removes mass, angular momentum and energy
  – Mass accretion<<mass supply
  – Hydromagnetic for low mass supply rate
  – Radiatively driven for high mass supply rate?
  – **Accretion** efficiency always high ~ $0.1c^2$

RB & Begelman 1999, 2004

These are radically different and distinguishable

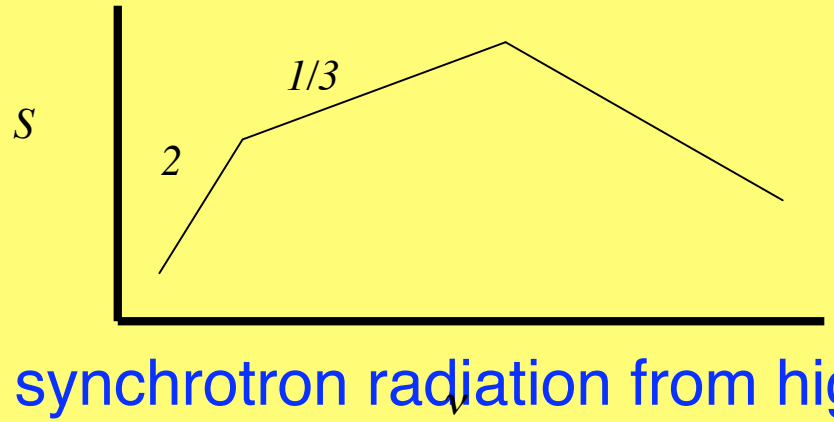
Self-Similar, Fluid, Disk-Wind Model

* Disk
  - Bound
  - Gyrentropic
  - Circulation
  - Inflow $\dot{M} \propto r^n$
* Wind
  - Thermal Front
  - Unbound
* Jet
  - Evacuated cone



Sketch Disk Model

* Radio spectrum $S \sim \nu^{1/3}$, $\nu < 1$THz
* $T \sim 10^{11} (\lambda/1\text{cm})^{5/3} (r/6\text{m})^{-2}$K
* Optically thin at all radii for $\lambda < 1$cm
* Superpose radiation from a range of radii
* Polarization (Broderick+B)



* X-ray emission from synchrotron radiation from high energy tail (cf Liu)
* Jet emission model also possible (Falcke)

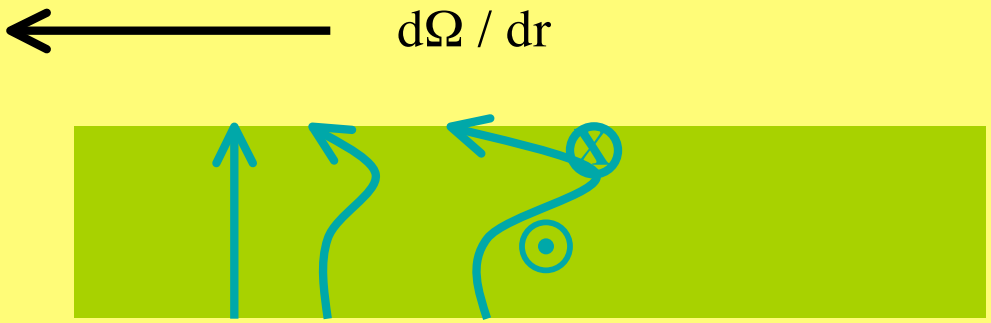
Sketch Disk Model

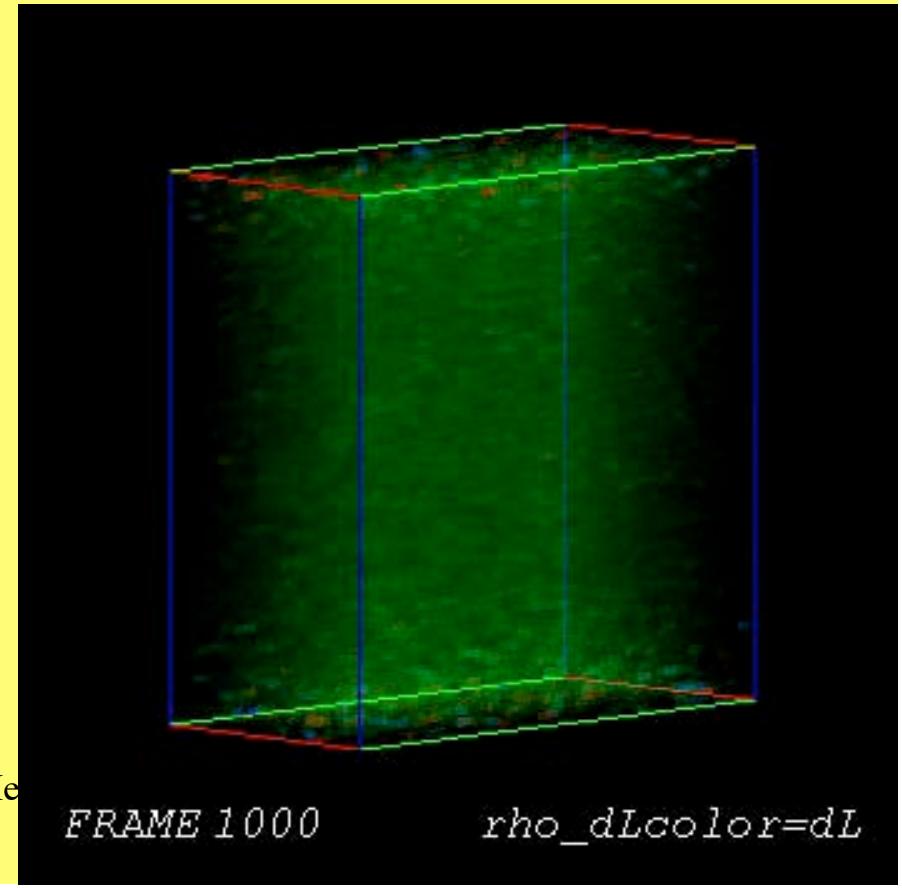
* $(dM/dt)_{sup} \sim 10^{21\text{-}22}$ g/s
* $(dM/dt)_{acc} \sim 10^{18\text{-}19}$ g/s
* Power release $\sim 10^{38\text{-}39}$ erg/s
* Luminosity $\sim 10^{36}$ erg/s => wind
  - eg 10^{21} g/s at 5000km/s
  - Shocks at $\sim (V/c_s)^{1/2}\, r_B \sim 1$ lt yr (cf Atoyan)
  - Could be competitive with colliding stellar winds
  - Particle acceleration site for H.E.S.S., GLAST photons?
    - 10TeV photons must originate outside10m

Real Disks are Magentized

* Magnetorotational Instability

Hawley et al



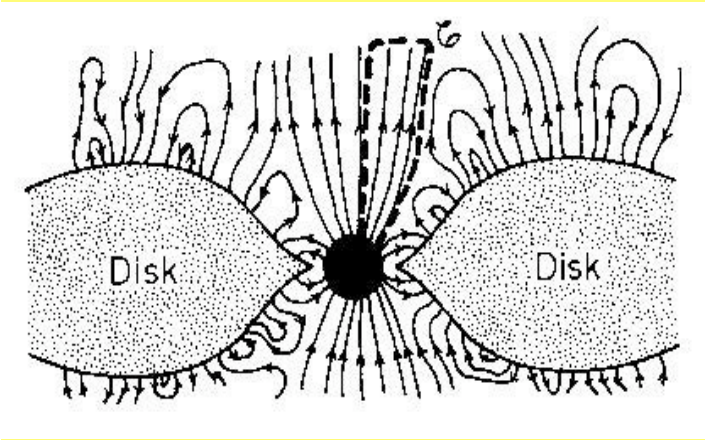


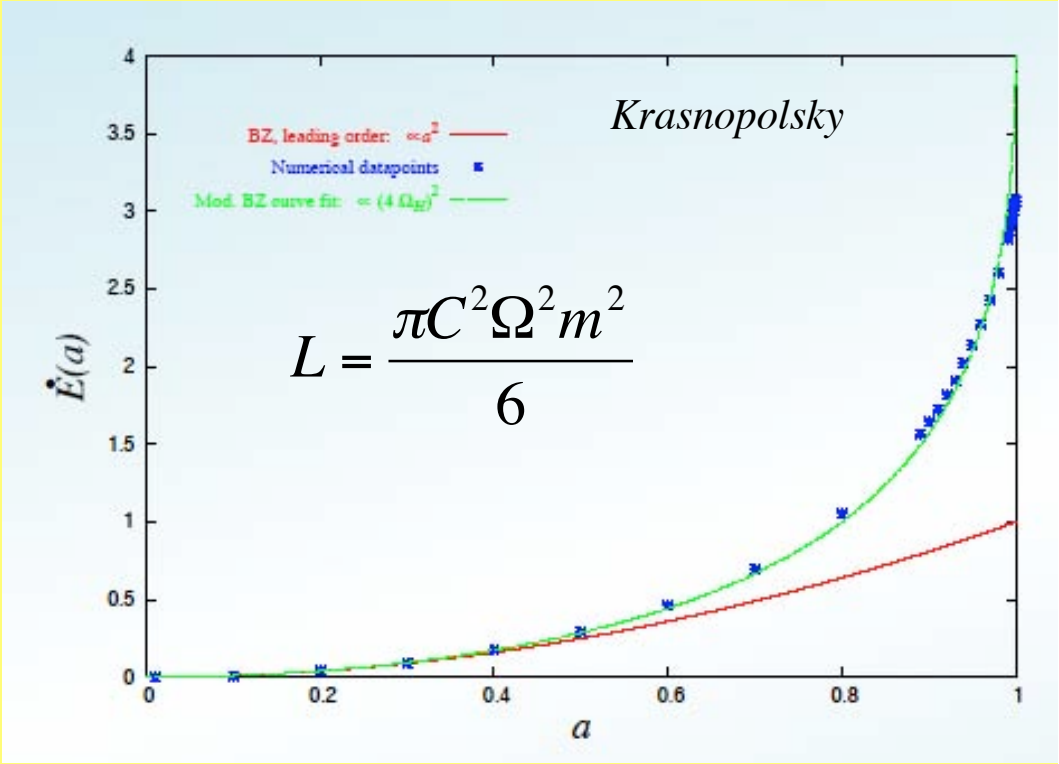
Jet/Outflow Formation

* Gas dynamics flows
* Hadronic jets
* Hydromagnetic wind launched from disk
  - Toroidal flux loops
  - Poloidal channels
  - Centrifugally-driven
* Electromagnetic-power from spinning hole
  - Collimated by disk wind
* Hybrid Models

Energy Extraction from Spinning Hole

* Electromagnetic extraction of energy from hole
* Causal?
* Efficient?

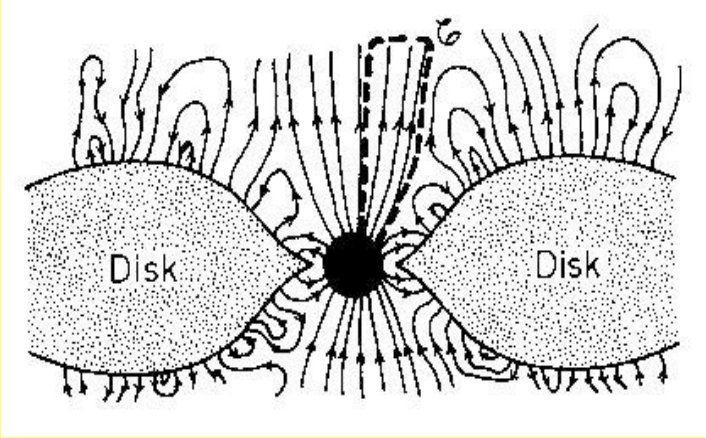




$$L = \frac{\pi C^2 \Omega^2 m^2}{6}$$

Also Gammie, Komissarov, Hawley, Koide et al

Unipolar Induction



* Rules of thumb:
* $\Phi \sim B R^2$; $V \sim \Omega \Phi$
* $I \sim V / Z_0$; $P \sim V I$

	PWN	AGN	GRB
B	100 MT	1 T	1 TT
ν	10 Hz	10 μHz	1 kHz
R	10 km	10 Tm	10 km
V	3 PV	300 EV	30 ZV
I	300 TA	3 EA	300 EA
P	100 XW	1 TXW	10 PXW

UHECR!

Simulations are transforming our understanding of disks

* MHD
* 3D
* GR
* Plot of magnetic energy density

Villiers et al

More Variations

* Energy transport
  - AC transmission (eg Spruit, Thompson)
    - eg chaotic electromagnetic fields with length scale ~ 100-1000 km, characteristic of the source variation
      - *E~B as relativistic*
    - Dynamically like radiation-dominated outflow
      - *Scalar pressure*
      - *No active collimation*
    - Natural particle acceleration mechanisms

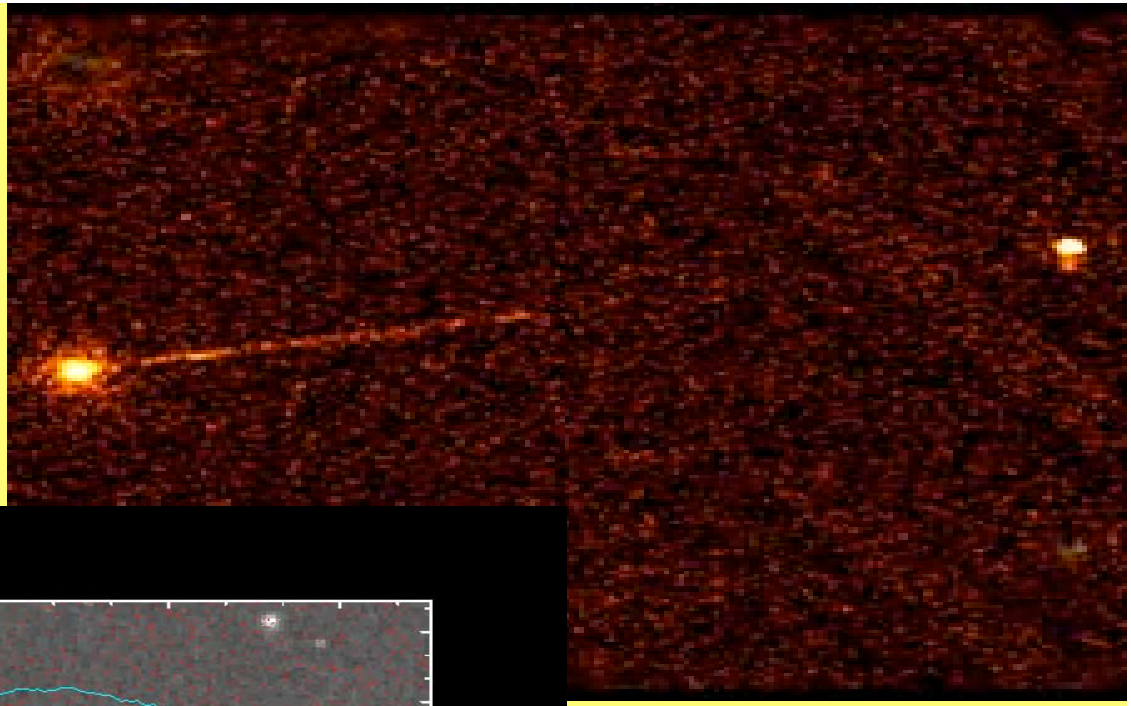
More Variations

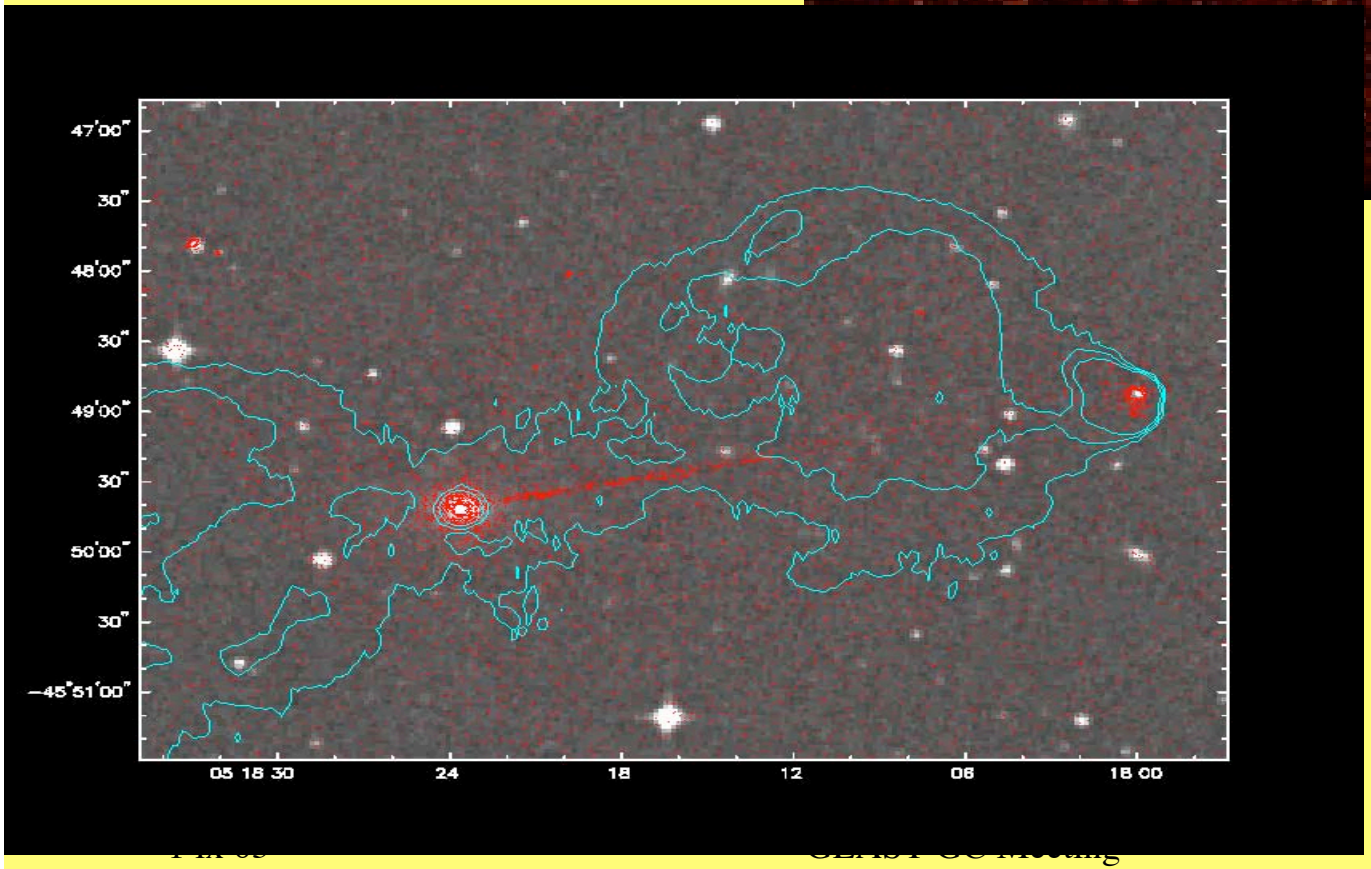
* Energy Transport
  - Local DC transmission
    - Episodic ejection of magnetically-confined jet segments
    - No large scale current circuits
    - Relativistic motion
    - Changing polarity of parallel field reflects changing polarity of disk field
    - Disk may eject loops of toroidal field or be launched and collimated by vertical field

More Variations

* Energy transport
  - Global DC transmission
    - Large scale order in magnetic field
    - Large scale current circuits
    - Toroidal magnetic field dominates parallel field far from the source
      - *If flux is conserved, parallel field ~ (Area)$^{-1}$*
      - *If current conserved toroidal field ~ (Area)$^{-1/2}$*
    - E~B still and energy carried by Poynting flux ~ B^2c
      - *Center of momentum frame moves relativistically*
    - Need equipartition particle pressure along axis to oppose hoop stress of toroidal field in comoving frame.

Pictor A

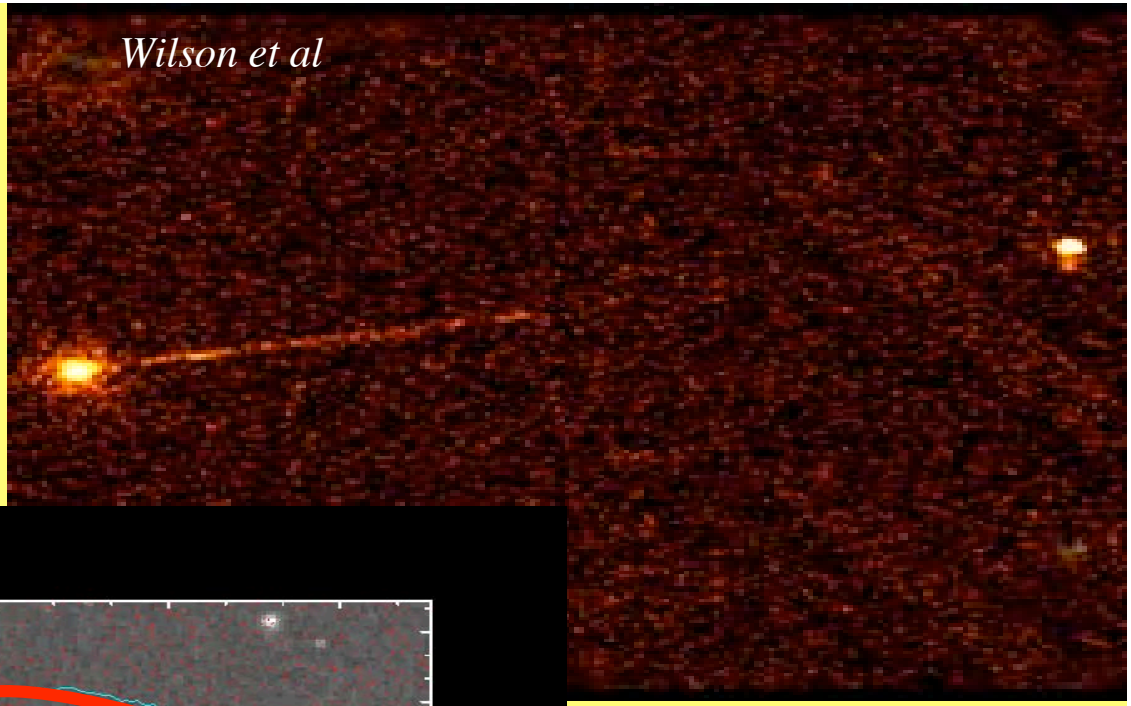


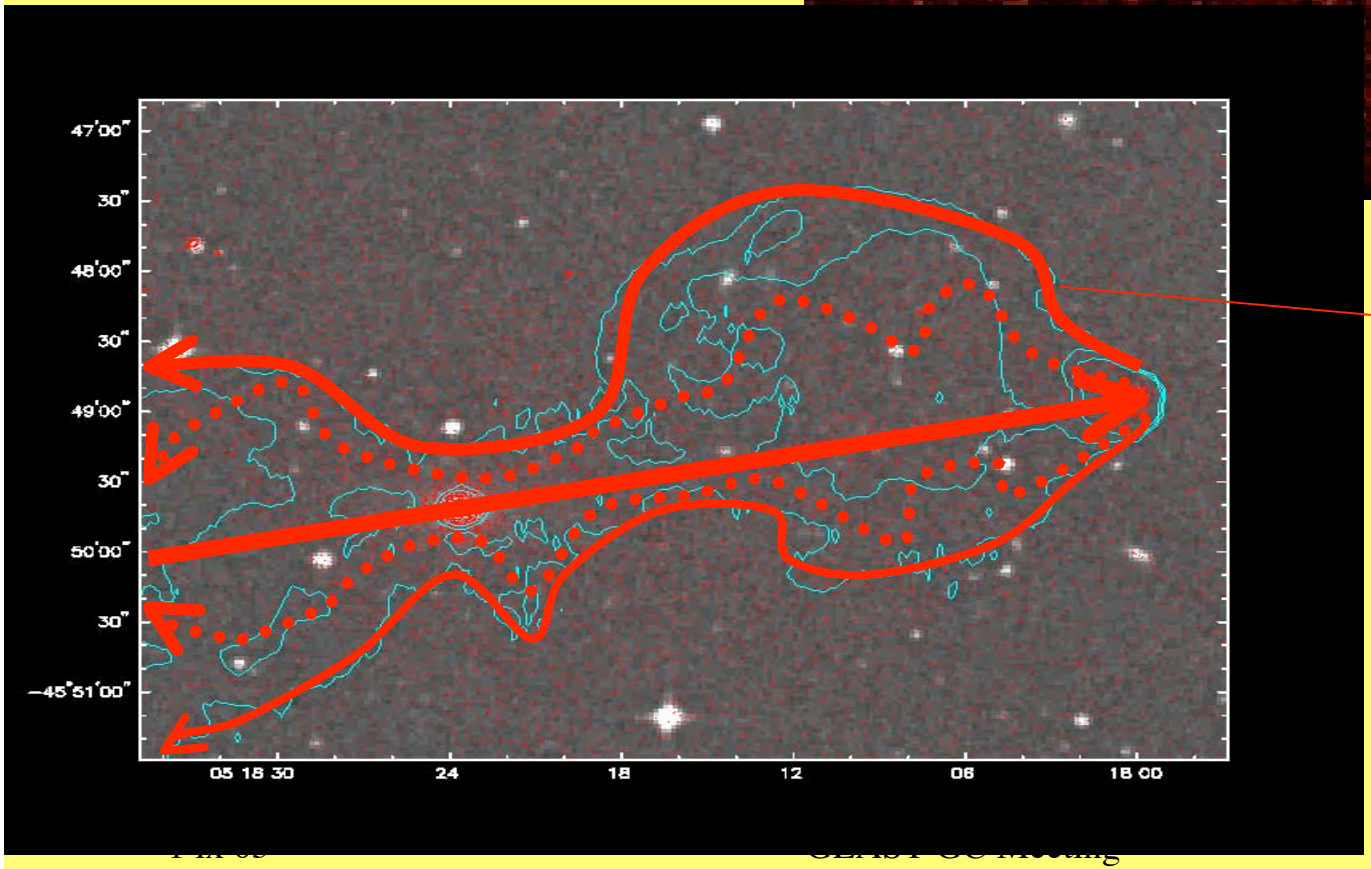


Magnetic Pinch?

Pictor A

Electromagnetic Transport
10^{18} not 10^{17} A
DC not AC
No internal shocks
New particle acceleration mechanisms





Current Flow

Nonthermal emission is ohmic dissipation of current flow?

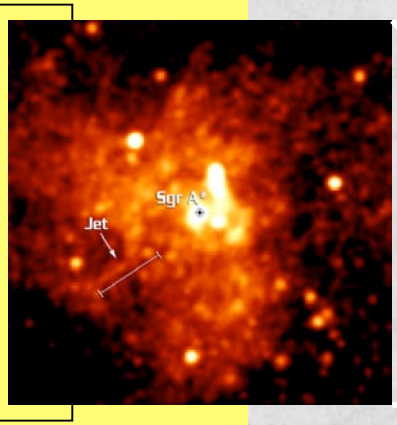
Pinch stabilized by velocity gradient

Equipartition in core

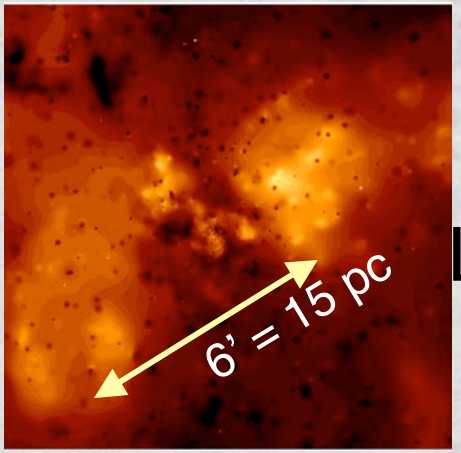
IGN

Baganoff, Morris etal

Sgr A* Jet?
Φ~3PV
I~300TA
L_{EM}~10^{30}W
L_{wind} 10^{32}W



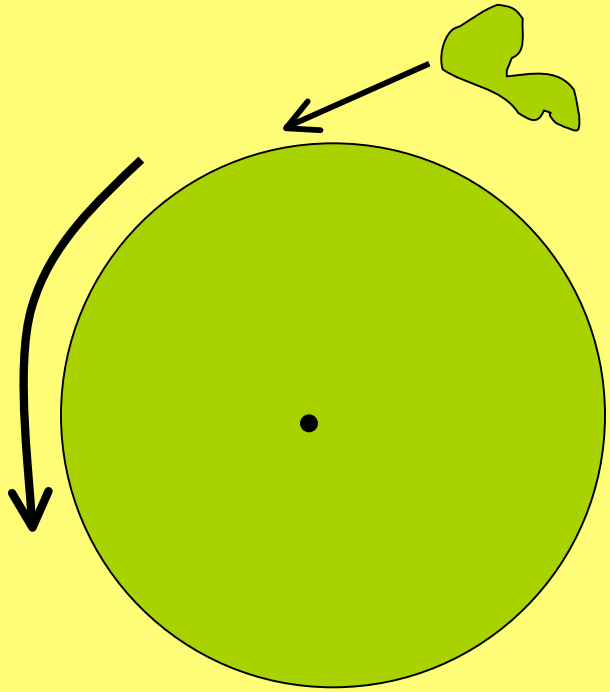
Magnetically-pinched current?



L_{lobe} ~ 10^{32} W?

Archimedean Disks

* $r_{out} \sim (c/v_{out})^2 r_{in} \sim 10^6 r_{in}$.



RB, Wang et al

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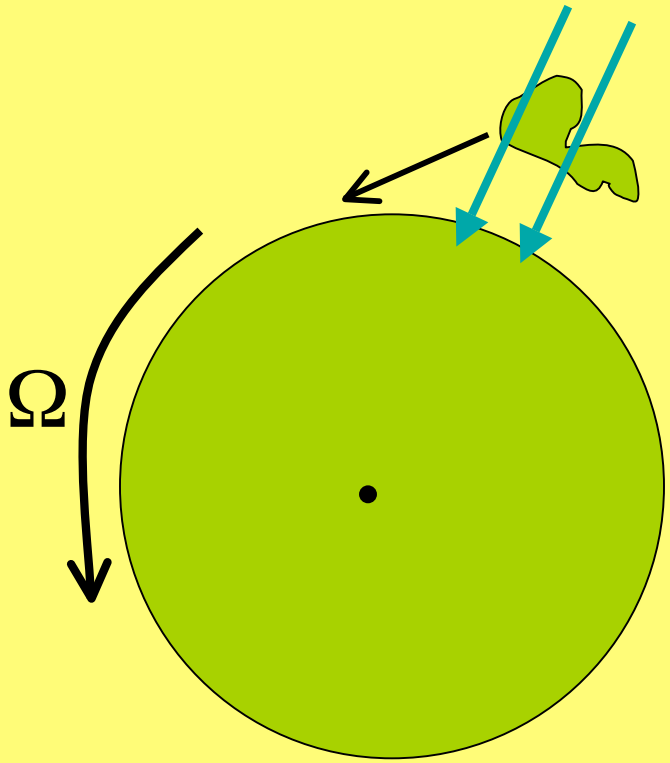


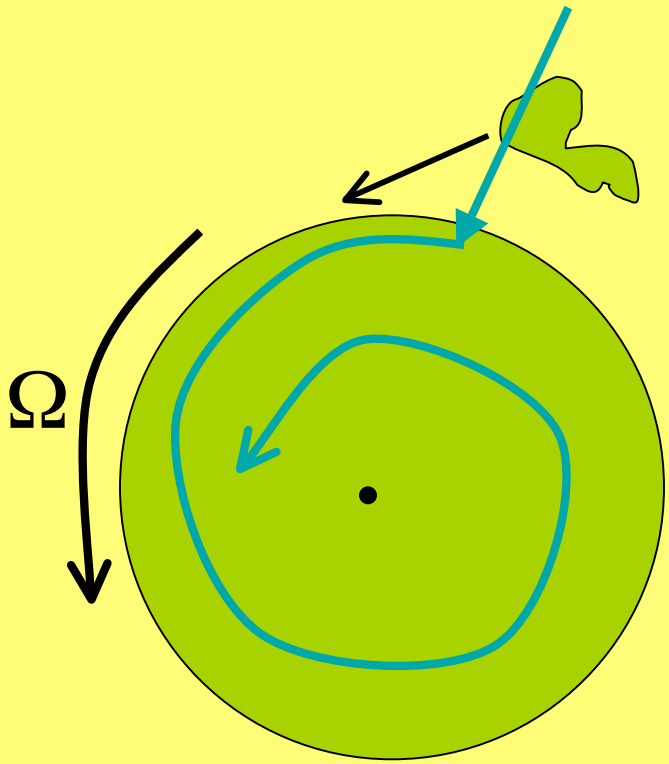
Archimedean Disks

* $r_{out} \sim (c/v_{out})^2 r_{in} \sim 10^6 r_{in}$.

$$B_r \propto r^{-2}$$

$$P_{mag} \propto r^{-4}$$

$$P_{gas} \propto r^{-5/2}$$

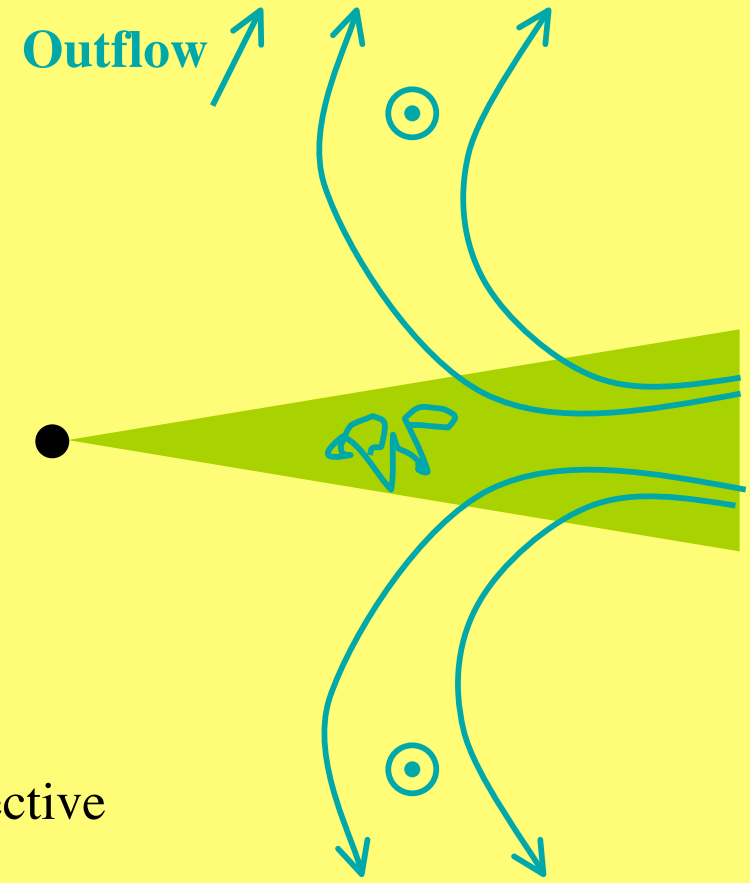


Net radial field
Conservative disk
Ignore irradiation, self-gravitation etc

Magnetic pressure dominates and field lines escape

Twister

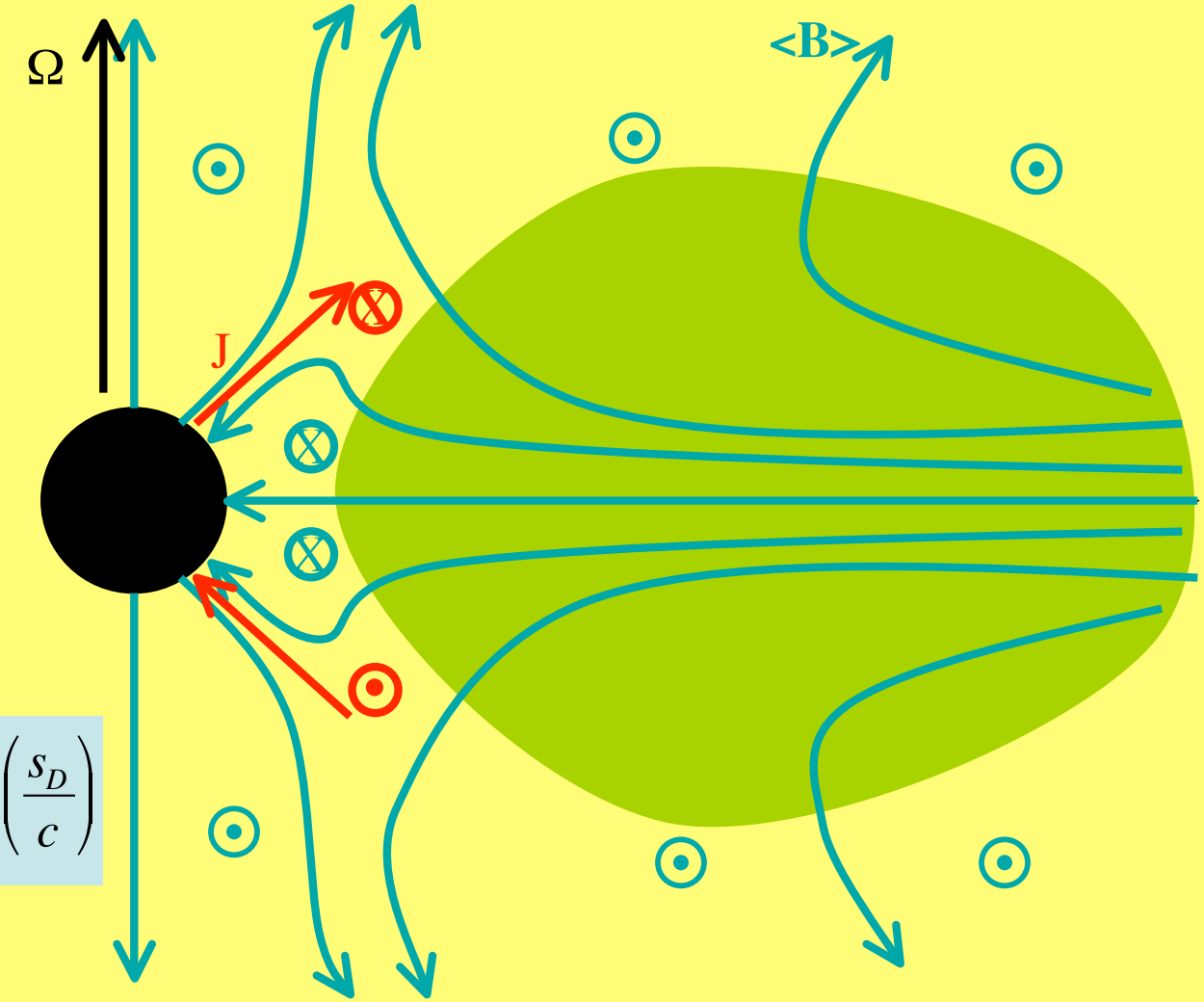
$$< B_r > \sim < B_\phi > \sim \left(\frac{r}{H}\right) < B_z > \propto r^{-5/4}$$



- Mean field configuration is MRI unstable.
- Growth time ~ Period
- $\lambda < H$
- **Conjecture**
  - Mean field is responsible for the torque
  - Random component is responsible for effective resistivity and viscosity

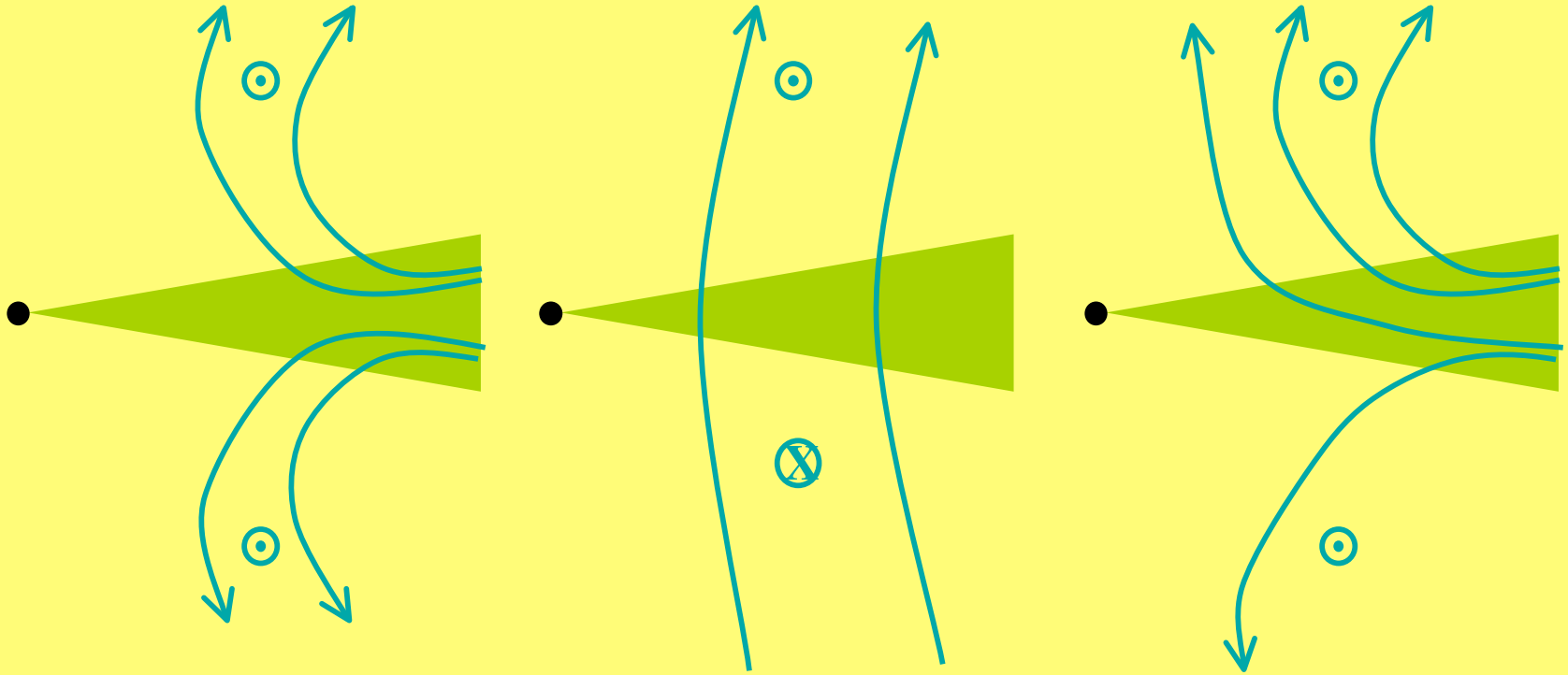
Test with numerical simulations

Inner Disk - Black Holes



$$\frac{L_H}{L_D} \sim \left(\frac{1}{\alpha_D \beta_D}\right)\left(\frac{\Omega_H}{\Omega_D}\right)^2\left(\frac{s_D}{c}\right)$$

Asymmetric Outflows/Jets

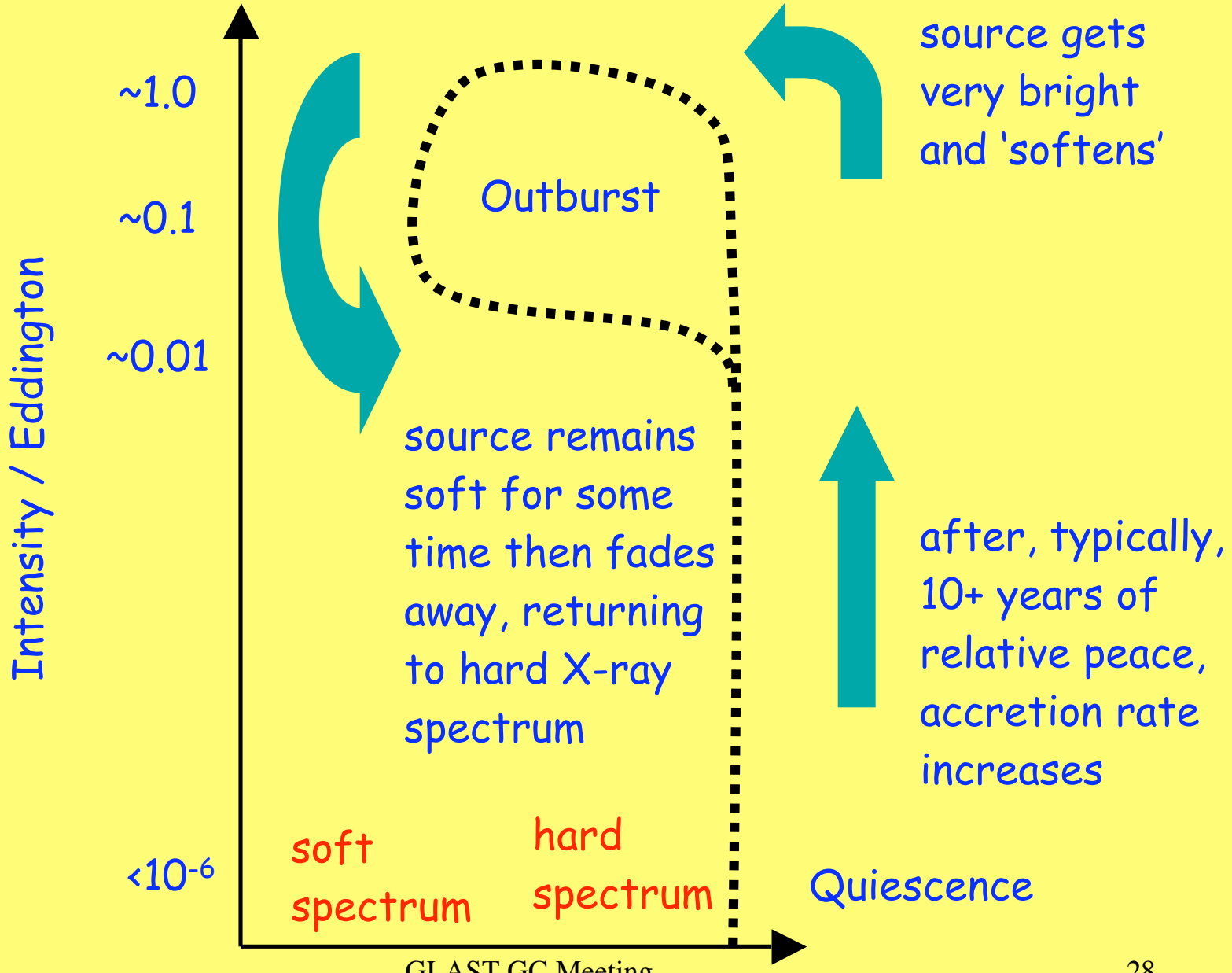


Even Parity **Odd Parity** **Mixed Parity**

Can you measure the toroidal field pattern?

Quasars for the Impatient

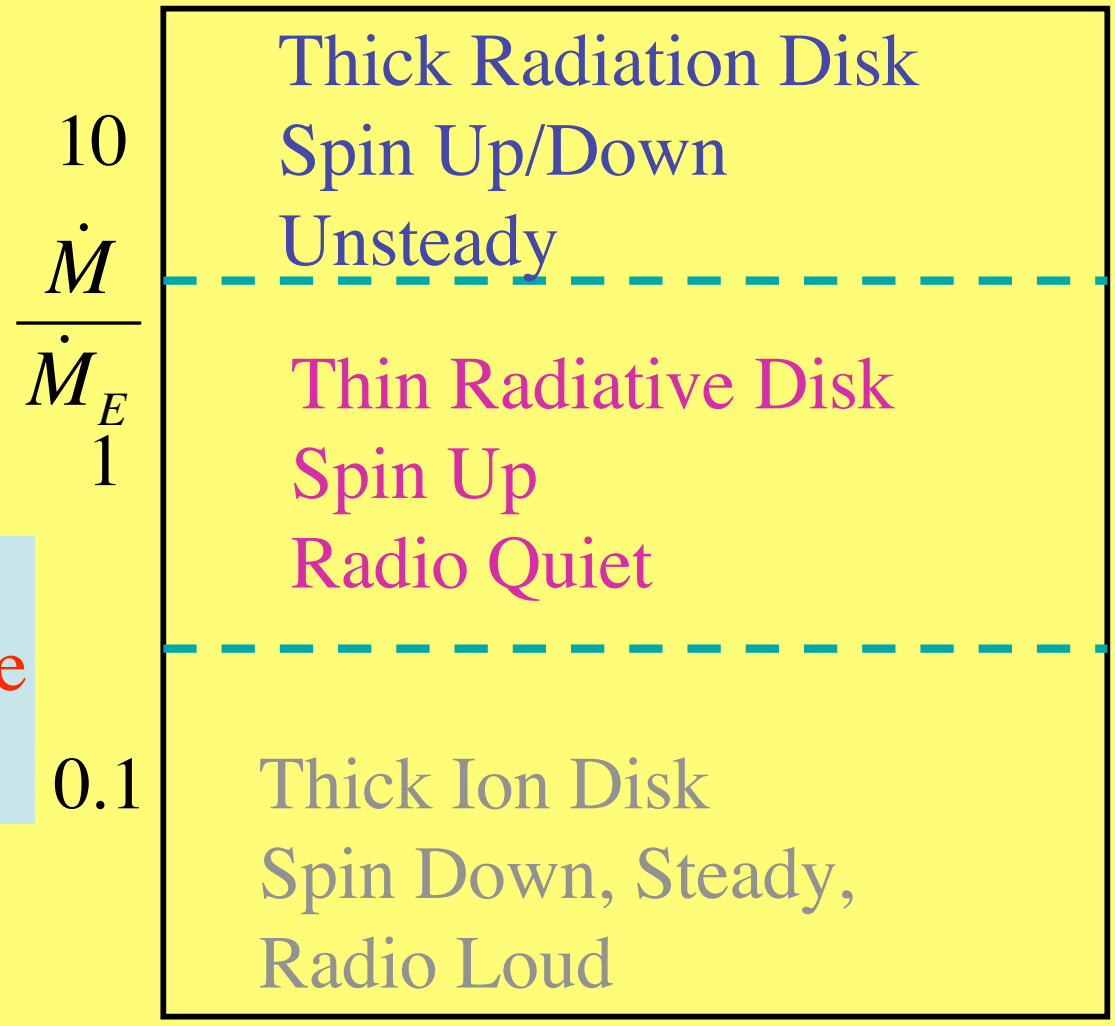
Fender



Jet Fuel

* Relativistic Jets Powered by Black Hole Spin
* Thick disks spin down hole electromagnetically
* Thin disks spin up hole through accretion

Jet properties depend upon mass supply rate and history.



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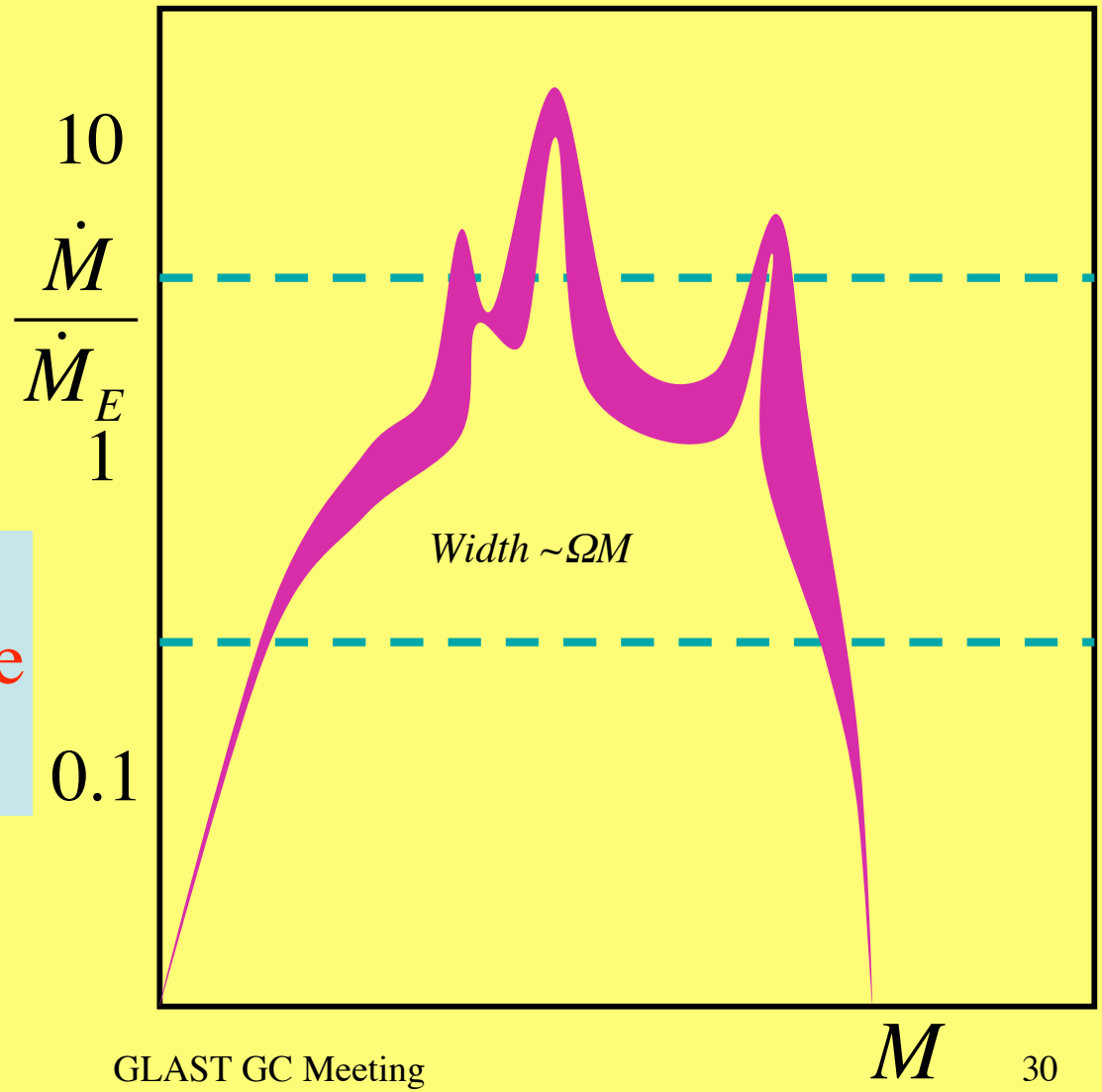

Summary

* Sgr A* disk may drive large outflow contributing to bipolar lobes and X-ray jet
* Reasonable interpretations of disk spectrum
* TeV emission does not come from Sgr A* hole
* GLAST observations may help us understand IGN like Sgr A*
* Blazar GeV emission comes from relativistic jets
* GLAST observations should diagnose the jet composition and dynamics